Adaptive Focal Plane Array - A Compact Spectral Imaging Sensor

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Motivation for LWIR / MWIR Adaptive FPA

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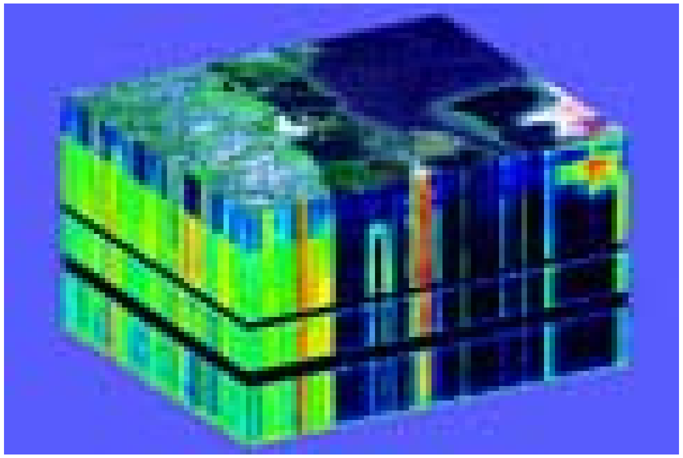
Adaptive Focal Plane Array
"Own the Night"



- Conventional hyperspectral imaging systems
  - Large and Heavy
  - Generate large volumes of data
  - Typically scanning systems
- Conventional multispectral imaging systems
  - Fixed detection wavelengths limit capability

AFPA Objective: Develop a compact spectral imaging sensor to enable enhanced target detection / ID in a device that can be deployed on SWAP-constrained platforms and provide real time information

- Wavelength tuned LWIR (8 – 11 μm / $\Delta\lambda$ FWHM ~ 100 nm)
- Simultaneous pixel-registered broadband MWIR (3 – 5 μm)
- Spatially resolved, intelligent spectral analysis

AFPA Parameter Objectives

- MEMS tunable filter array integrated with a dual-band focal plane array
- Parameters:
  - Tuning range (individual filters or checkerboard): 8.0 µm ⇒ 11.0 µm
  - Filter bandwidth (FWHM): 100 nm ± 20 nm @ 10.0 µm
  - MWIR detection band: ~ 3.5 – 5 µm (nominal)
  - Filter dimension: ~ 400µm center-to-center spacing
  - Filter optical fill factor: ≥ 50%
  - FPA/ROIC: 640x480 20µm DB-FPA
  - Filter format: Spectral fovea (nominally 8 x 24 filters)
  - Operating temperature: ~ 80K
  - Filter tuning speed: ~ 1 msec

TS&I MEMS Filter / AFPA Architecture (Notional)

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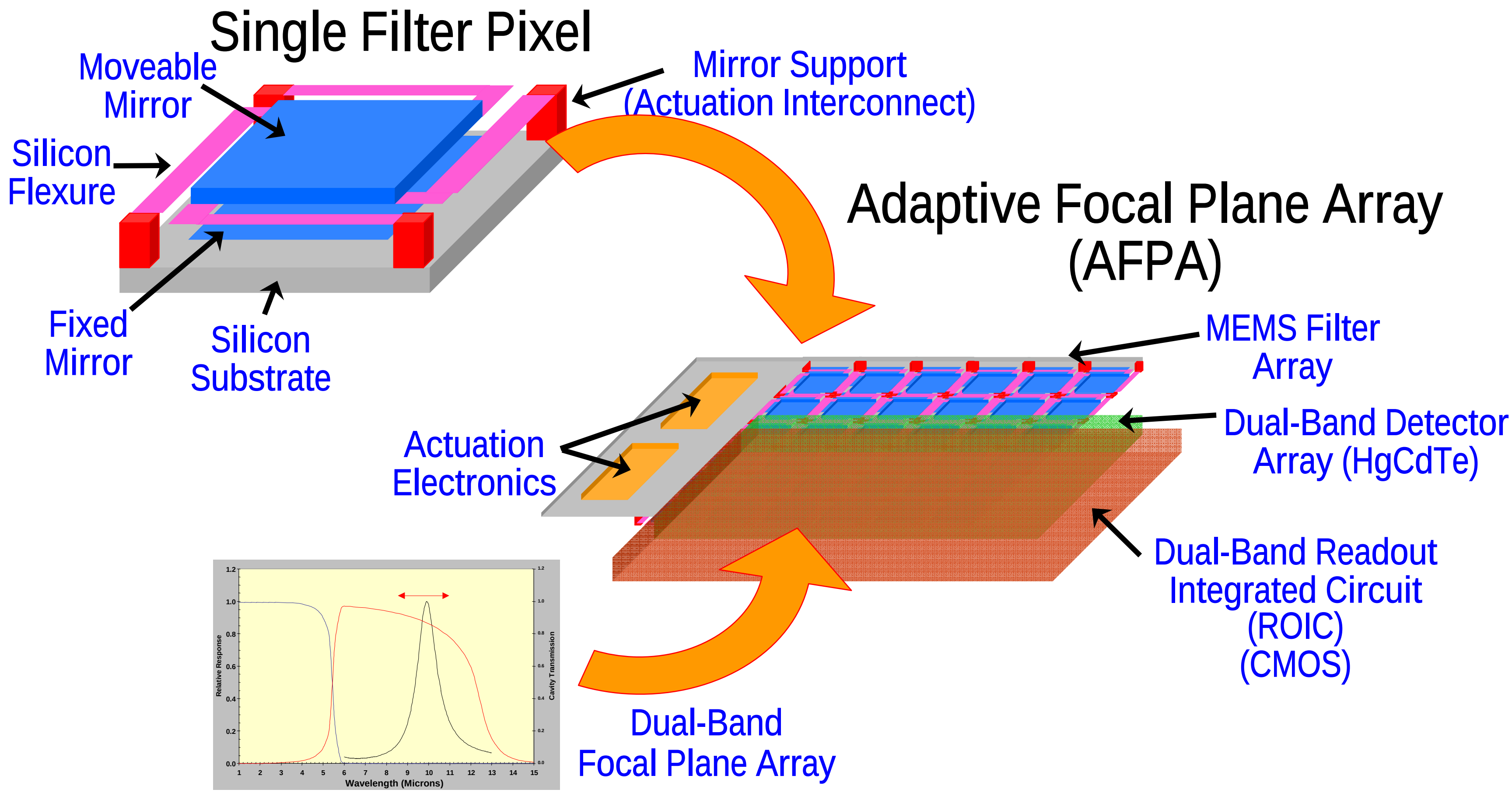

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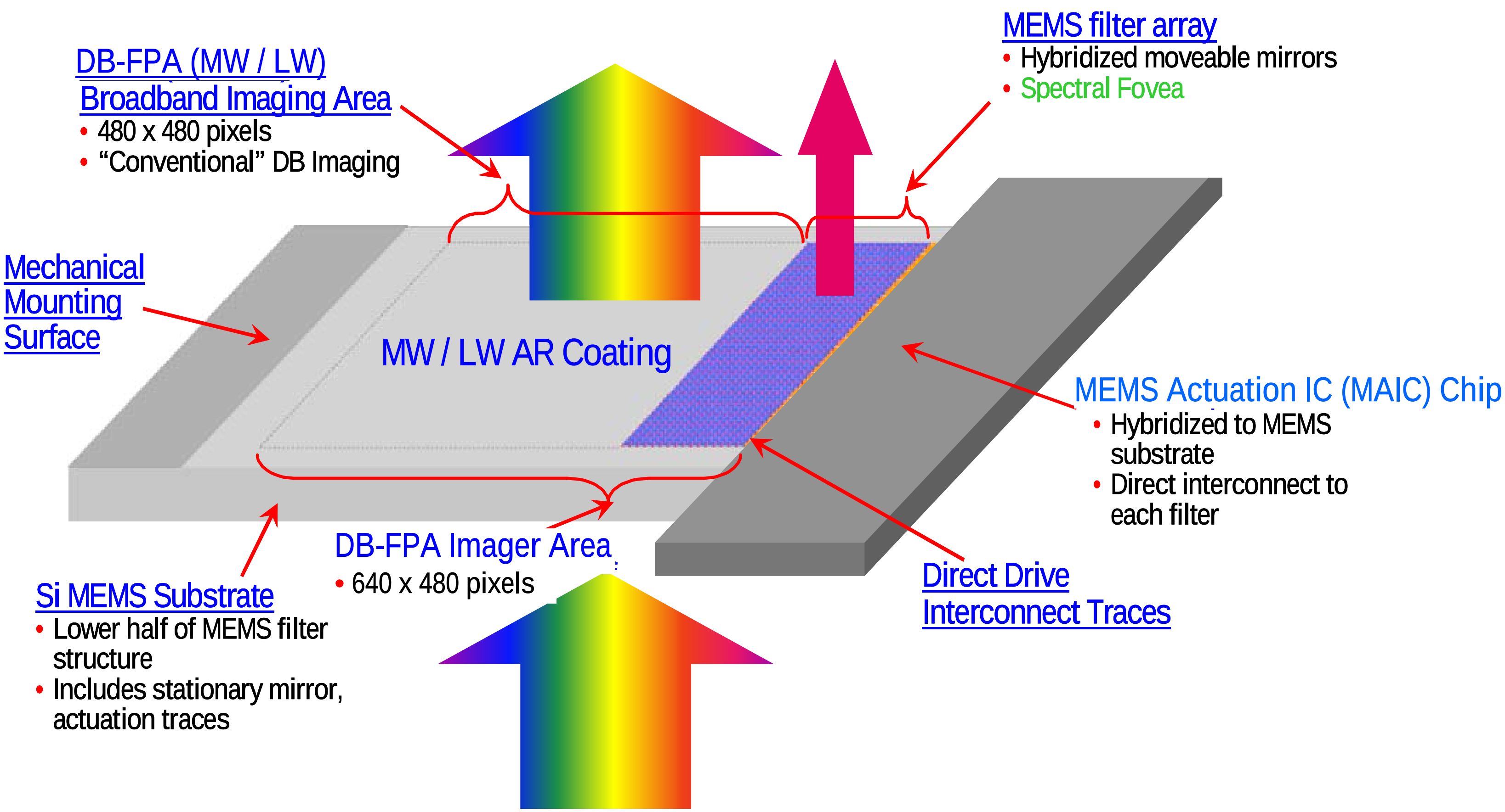
AFPA Phase II MEMS Tunable Filter Array



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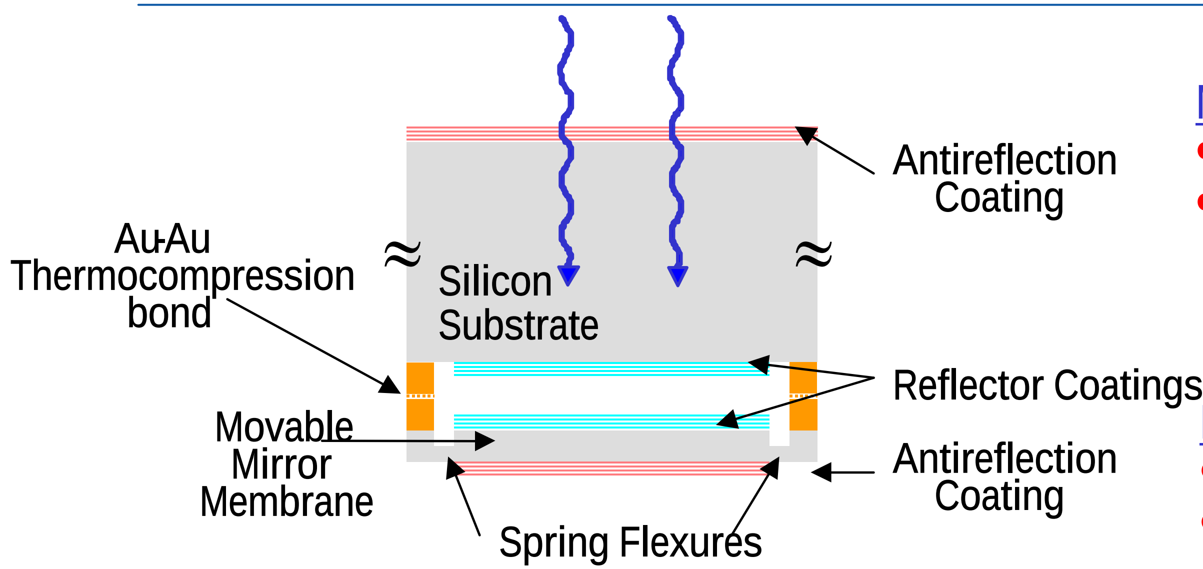
MEMS Fabry-Perot Filter Design



MEMS structure

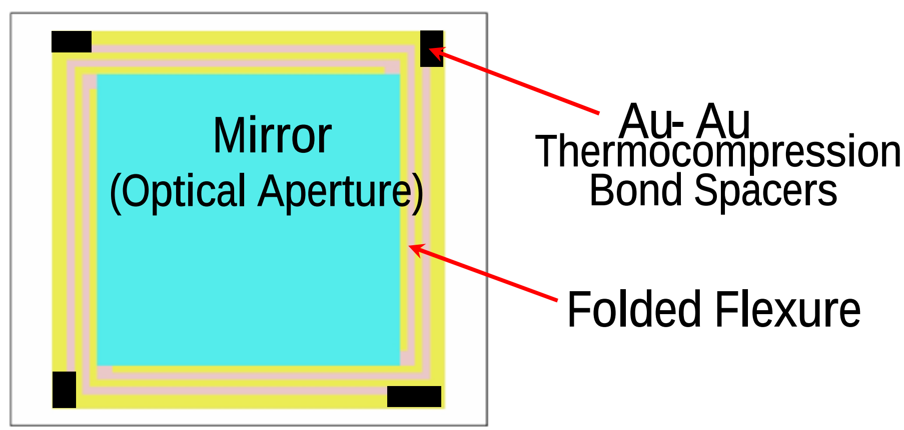
- Bulk micromachining
- Hybrid assembly using Au-Au thermocompression bond

Filter characteristics

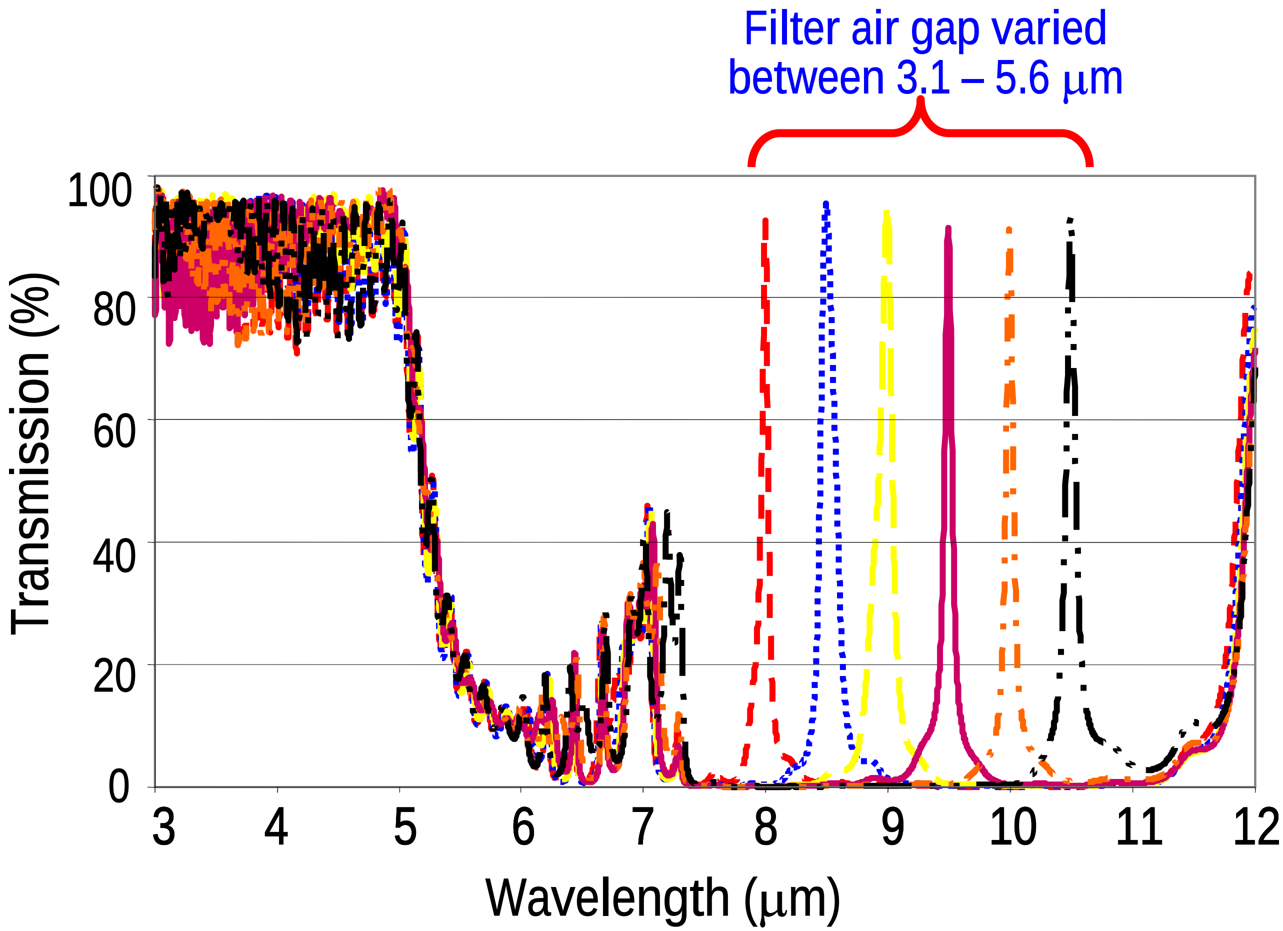
- Fabry-Perot filter design
- Tuning band determined by reflection band of dielectric mirrors

Filter Actuation

- Filter actuated by applying potential between moveable mirror and substrate mirror
- Displacement driven by electrostatic attraction
- Restoring force provided by Si flexure springs
- Prototype devices - direct drive



Modeled MWIR / LWIR Spectral Performance
(Transmission Averaged over F/6.5 Incident cone)



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MEMS Filter SEM Images

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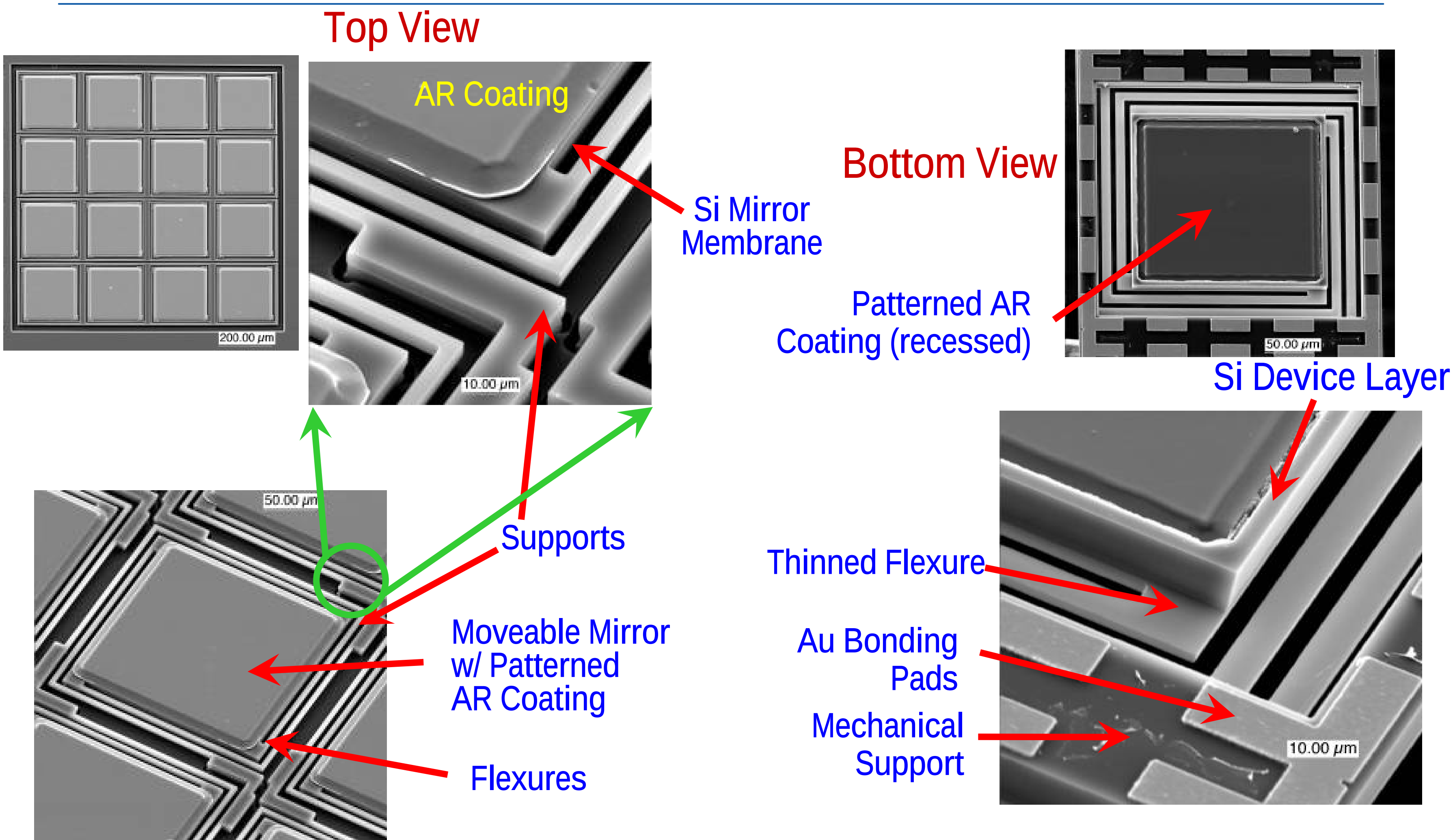

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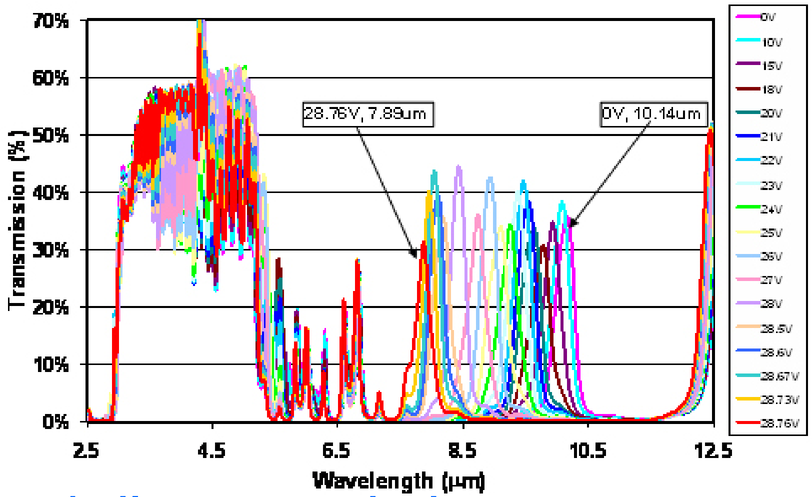
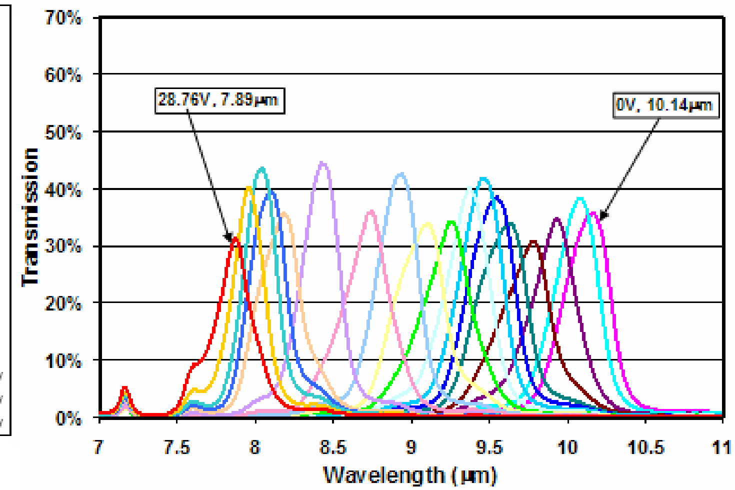
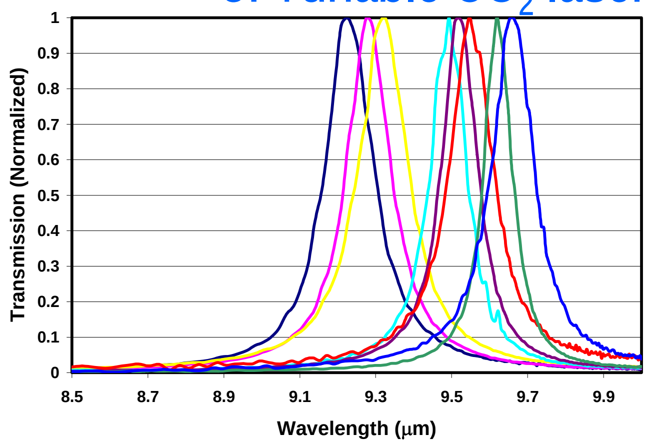
MEMS Tunable Filter
Measured Optical Performance

IR Microscope Transmission



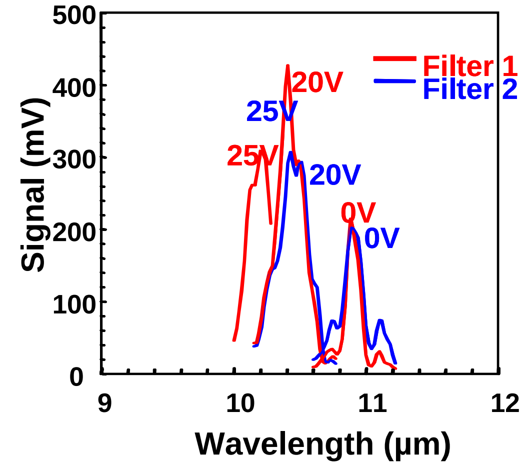


Scanned Filter Transmission of Tunable CO_2 laser



CO_2 Laser Wavelength (µm)	Filter Bandwidth (nm FWHM)
9.23	144
9.28	138
9.32	145
9.49	108
9.52	112
9.55	145
9.62	90
9.66	129

LWIR Detector Spectral Response with Tunable MEMS Filter



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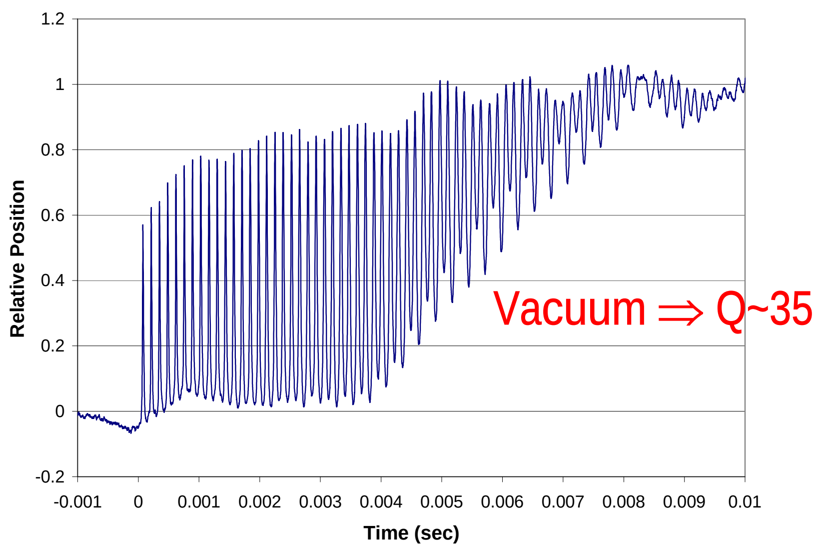
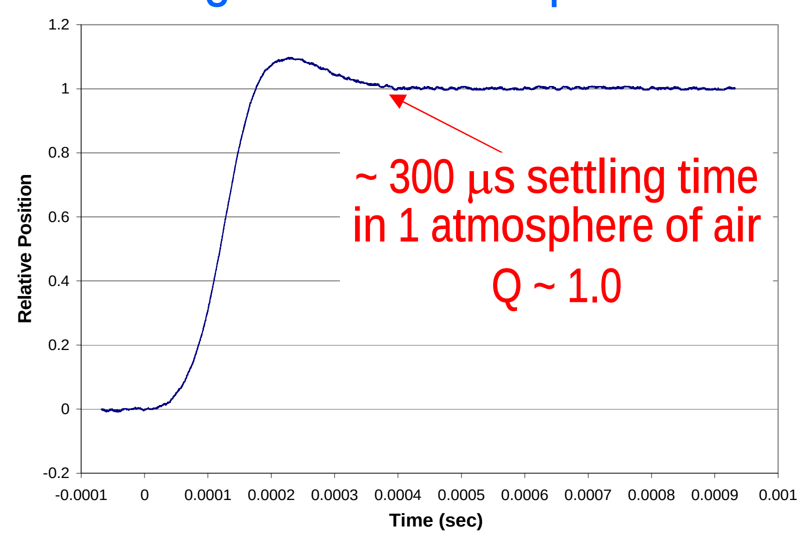
Tunable MEMS Filter Mechanical Response

- Low energy dissipation in Si MEMS structure leads to mechanical “ringing” under vacuum operation
  - 300μs in air, but may be >10’s (or even 1000’s) msec in vacuum
- Exploit gas damping for increased response speed
  - Requires sealed, backfilled package
  - Neon gas provides necessary viscosity for 77K operation

MEMS Filter Response to Voltage Actuation Step





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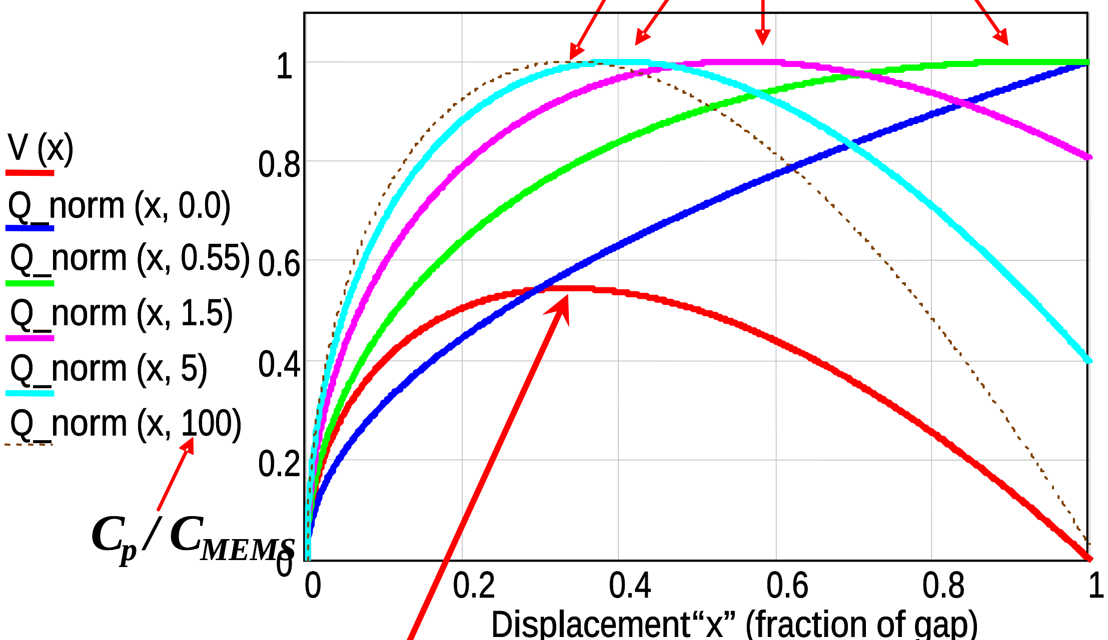
AFPA Phase II Imaging Device Objectives

- Demonstrate full capability MEMS filter array
  - Individual, independent filter tunability
  - Extended tuning range: 8.0 – 11.0 µm
  - Narrower bandwidth: 100 nm ± 20 nm @ 10.0 µm
  - Design and implement CMOS MEMS Actuation IC (MAIC) for full array actuation
- Demonstrate prototype AFPA sensor
  - Imaging structure with tunable MEMS array coupled with dual-band FPA
  - Demonstrate spectral tunability in an imaging array
  - Spectral Fovea configuration
- Technical challenges
  - Overcome tuning limit imposed by MEMS snap-down phenomenon
    - Optimized optical filter design
    - Implement negative capacitance MEMS actuation to overcome parasitic
    - Provide viscous MEMS damping
  - Heterogeneous technology integration in an integrated optimal subsystem
    - Tunable MEMS filter array coupled to DB-FPA in a compact, gas-filled, optical, cryo-enclosure

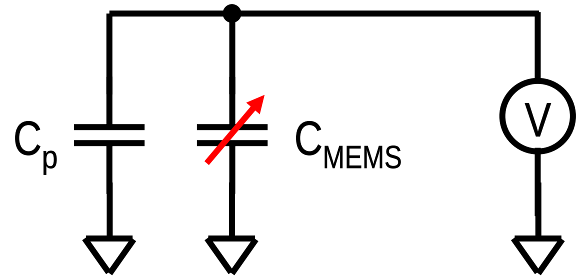
MEMS Actuation and Snap-down

Maximum in Q(x) curve corresponds to charge snap-down limit



Theoretical maximum MEMS deflection before snap-down using voltage control

(33% of unactuated gap)



- Charge control enables tuning beyond snap-down
- Limited by parasitic capacitance between driver and MEMS device
- Negative capacitance circuit can overcome C_p
- Requires low MEMS Q to prevent oscillation past stable point
- Optimize optical coatings to maximize tuning slope / minimize demands on $-C_p$ tuning

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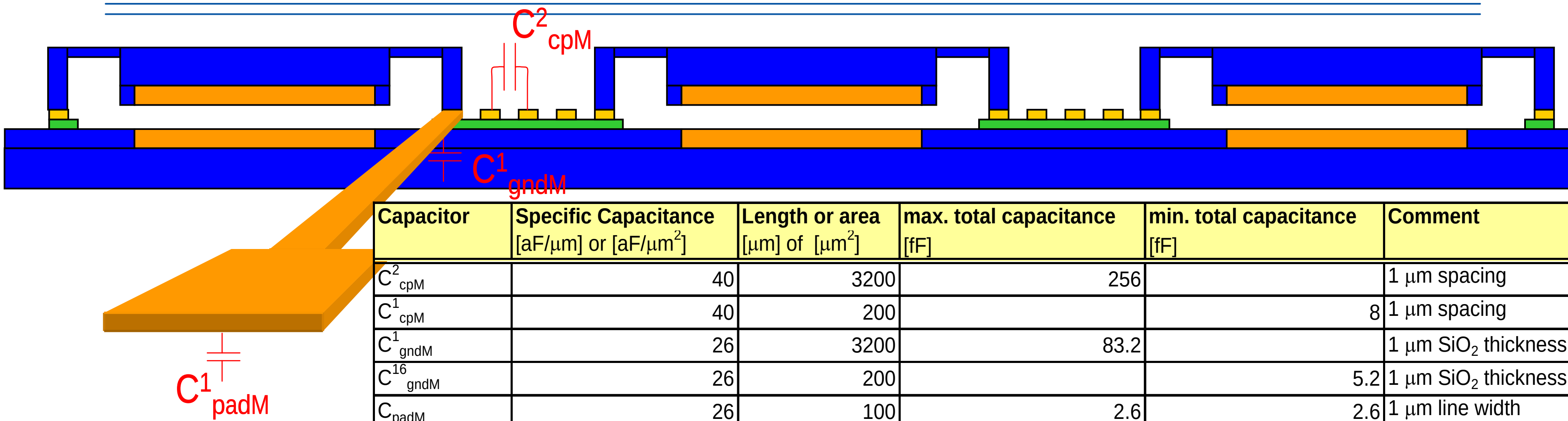
Primary Sources of Parasitic Capacitance



Capacitor	Specific Capacitance [aF/μm] or [aF/μm²]	Length or area [μm] of [μm²]	max. total capacitance [fF]	min. total capacitance [fF]	Comment
C^2_{cpM}	40	3200	256		1 μm spacing
C^1_{cpM}	40	200		8	1 μm spacing
C^1_{gndM}	26	3200	83.2		1 μm SiO_2 thickness
C^{16}_{gndM}	26	200		5.2	1 μm SiO_2 thickness
C_{padM}	26	100	2.6	2.6	1 μm line width
Total to GND			85.8	7.8	
Total coupling			256	8	
Total			**341.8**	**15.8**	

- Parasitic Capacitance dominated by coupling capacitance
  - Values depend position inside filter array
  - Largest parasitic cap determines tuning range for entire array
- MAIC will add similar capacitance
- Negative capacitance actuation circuit under development to overcome C_p limited snap-down

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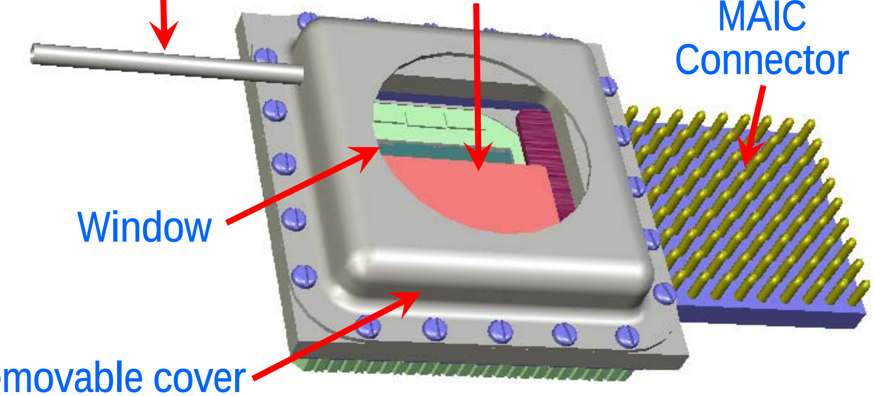
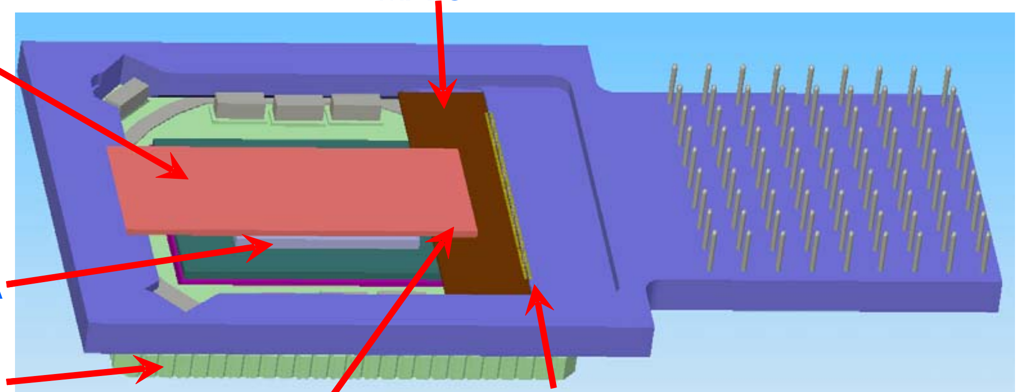
Integrated AFPA Assembly (Conceptual)

- Gas filled enclosure enables viscous gas damping of MEMS filters
- Resealable cover enables reuse and testing of MEMS filter array component



- MAIC / MEMS array interface key to achieving tuning beyond snap-down



Planned AFPA Prototype Demonstration

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Lab bench level testing planned using prototype AFPA sensor

- Demonstration of LWIR spectral response tunability
  - Independent filter actuation
- Demonstration of spectral analysis capability
  - Synthetic input spectra (filtered illumination)
  - Target materials if military interest
- Demonstration of spectral imaging of scene (lab)
- Demonstration of simultaneous LWIR tuning / broadband MWIR imaging
- Future development of field-testable camera with integrated optimal spectral interrogation and analysis algorithms

Summary

- Phase I - LWIR tunable MEMS filter capability demonstrated
  - Tuning range 8.0 – 10.0 µm
  - Filter bandwidth 90 – 150 nm
  - Tuning speed ~ 1 msec
  - Simultaneous broadband MWIR transmission
  - Filters as small as 280 x 280 µm
- Phase II - Integrated dual-band AFPA sensor configuration established
  - Spectral fovea configuration
  - Wide tuning range (8.0 – 11.0 µm) achievable using novel actuation and optimized optical design
  - Independent filter tunability
  - Sensor package combining MEMS array, CMOS MAIC, Dual-band FPA with mechanical MEMS damping
  - Optical configuration requires minimal optical imaging sensor modifications

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